Comparison of the effect of locking *vs* standard screws on the mechanical properties of bone-plate constructs in a comminuted diaphyseal fracture model

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1 Introduction

Healing of comminuted diaphyseal fractures is a major consideration in orthopaedics as they are frequently encountered, demonstrate a high rate of complications and their treatment is often challenging. They are often treated by bridging osteosynthesis for which the implant must withstand all weight-bearing forces until sufficient bridging callus is formed. One of the latest available implant in this indication is the Locking Compression Plate (LCP) whose combined holes accept either standard or locking screws.

Although there are a few clinical and biomechanical studies comparing LCP plates featuring locking screws with non-locking plates, the real advantage of locking screws remains undefined and unquantified. The purpose of this *ex vivo* study was to compare the mechanical properties of bone-plate constructs with LCP plates used either with standard screws or with locking screws on an experimental model of comminuted fracture.

2 Methods

Twelve pairs of ovine tibia were harvested and packed with gauze soaked in isotonic saline solution before freezing (-24°C). After thawing at room temperature, they were kept moistened throughout the experiment. Inclusion criteria were skeletally mature animals belonging to one single breed, similar size of tibia and absence of bone diseases evaluated on radiographs. They were randomly divided into 2 equal groups.

A model of comminuted fracture (mid-diaphyseal 5-mm gap) was created on the left tibia from each pair and treated with a 8-hole, 4.5-mm, broad stainless LCP plate with 3 bicortical self-tapping screws in each fragment. In group 1 (n=6), 4.5 mm cortical screws were placed in slightly inner eccentric position (to avoid collapse of the osteotomy site during weight-bearing). In group 2 (n=6), 5.0 mm locking screws were used. All screws were tightened using a torque-limiting screwdriver at 4 Nm.

Biomechanical evaluations were performed by non-destructive tests at quasi-static displacement rate (1 mm/min) on electromechanical systems. Four-point bending, torsion and axial compression loading conditions were applied one after the other on plated bones and on intact contralateral bones, to serve as a control. Maximum load used for non-destructive tests was about 50% of yield load, as previously assessed by destructive tests on pre-test plated bones. Bending was performed in a latero-medial direction with upper anvils surrounding bone gap. After embedding of proximal and distal ends in polyurethane casting resin, bones sustained clockwise torsional load, then axial compression load.

For bending and compression on plated bones, 2 monocortical 1.5 mm pins were seated through the lateral cortex (2.5 mm outside the edges of bone osteotomy). A laser scan micrometer allowed continuous measurement of width between pins during tests.

Crosshead displacement, load, angle of rotation, torque and width between pins were recorded at 10 Hz.

Extrinsic stiffness of bone-plate constructs (K) was calculated, as well as stiffness loss (Kr) compared with contralateral tibia. Slope of the load-gap displacement curve (S) was also calculated. K and Kr provide information on global mechanical properties of plated or intact bone, whereas S is a reflection of interfragmentary motion during load thus providing information on local mechanical properties close to the osteotomy gap.

Results were statistically compared between the 2 groups by a 2-way ANOVA and Tukey's Post Hoc tests, for each loading condition with significance set at $P<.05$.

3 Results and Discussion

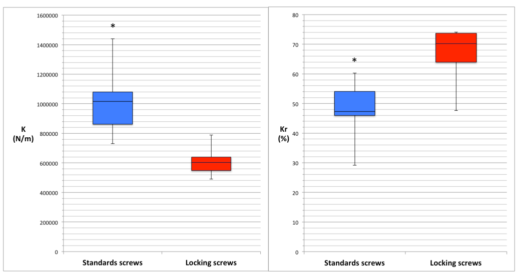
In 4-point bending, there were no significant differences between group 2 (G2) and group 1 (G1) for K (G2: 321.9 ± 65.2 kN/m, G1: 286.0 ± 36.6 kN/m), for Kr (G2: 55.4 ± 10.4%, G1: 64.5 ± 3.9%) and for S (G2: 292.0 ± 84.3 N/mm, G1: 271.4 ± 36.2 N/mm). In torsion, there were no significant differences between the 2 groups for K (G2: 133.3 ± 18.7 Nm/rad, G1: 117.2 ± 18.0 Nm/rad) and for Kr (G2: 44.0 ± 10.3%, G1: 55.0 ± 10.6%) (table 1).

Bending stiffness and torsion stiffness were not significantly different using locking screws or standard screws. That is consistent with most other *in vitro* and *ex vivo* studies comparing LCP with non locking (LC-DCP) plates [1] [2].
In compression, group 2 showed significantly lower K (611.1 ± 104.0 kN/m) and higher Kr (66.5 ± 10.3%) than group 1 (1019.2 ± 249.5 kN/m; 47.7 ± 10.8%) (table 1, figure 1). Compression stiffness with locking screws was about half compared with standard screws, whereas other studies showed significantly higher stiffness for locking screws [2] [3]. It might be related to 2 phenomena: i) the friction forces induced by the screws which compress the plate onto bone in standard osteosynthesis and ii) the limitation of bone displacement by the eccentric position of standard screws that are blocked on the inner part of the plate hole under axial compression whereas standard screws are usually placed in central position. Anyway, there was no significant difference between the 2 groups for S (G2: 254.6 ± 72.6 N/mm, G1: 438.2 ± 228.4 N/mm), meaning that the significant difference of global mechanical properties seems to have no significant effect on the local mechanical properties (table 1).

	Standard screws (G1)			Locking screws (G2)		
	K	Kr	S	K	Kr	S
4-point bending	286 007.22 ± 36 586.22	64.47 ± 3.87	271.35 ± 36.16	321 926.90 ± 65 244.02	55.44 ± 10.39	292.00 ± 84.33
Torsion	107.28 ± 16.46	54.98 ± 10.56	/	122.07 ± 17.10	44.01 ± 10.27	/
Axial compression	1.02E+6 ± 249 501.43	47.67 ± 10.77	438.24 ± 228.34	611 057.11 ± 104 012.99	66.50 ± 10.26	254.61 ± 72.56

Table 1 Mechanical properties of bone-plate constructs for each type of condition (mean ± SD)

K = extrinsic stiffness: slope of the graph showing the load or torque over the vertical displacement of the crosshead or the angular displacement of bone (N/m or Nm/rad)
Kr = stiffness loss: difference between extrinsic stiffness of the intact contralateral bone and extrinsic stiffness of the operated bone divided by extrinsic stiffness of the contralateral bone (%)
S = load-displacement curve slope: slope of the graph showing the load over the displacement of the two pins surrounding the interfragmentrary gap (N/mm)



a) extrinsic stiffness K   b) stiffness loss Kr

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Figure 1 Box plots comparing mechanical properties in axial compression for the 2 groups: Asterisks indicate significant differences between groups (P<.05). Whiskers lower and upper limits = 2.5th and 97.5th percentiles.

The main limitation to this *ex vivo* study is the only mechanical evaluation of bone-plate constructs, without assessment of bone healing. Now, bone healing results both of controlled mechanical conditions and of favourable biological conditions at the fracture site.
Further *in vivo* study is needed to compare the biological conditions of bone-plate constructs with LCP plates used either with standard screws or with locking screws. It may be conducted by assessing the mechanical properties of bone callus after bridging osteosynthesis according to the same experimental design.

4 Conclusions

Locking screws had no statistically significant effect on the mechanical properties of LCP-plated bones in 4-point bending and torsion, compared to standard screws. In axial compression, locking screws induced a significant decrease in global mechanical properties without significant decrease in local mechanical properties close to the osteotomy gap.
Our mechanical *ex vivo* study, completed by further *in vivo* study, should help to make a rational choice of the type of implant to treat comminuted fractures.

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